Superconducting Cavities for High Power Accelerators

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- CERN: E. Chiaveri
- Cornell: H. Padamsee
- KEK: T. Furuya and S. Mitsunobu
- LANL: My coworkers
- TJNAF: P. Kneisel

Outline

- **Review of the superconducting cavities used for:**
  - **High luminosity colliders (beam current ^{3} 500 mA)** **CESR, KEKB, LHC**
  - **High power proton linacs (Power ^{3} 1 MW)** **APT, SNS**
- **Some R&D issues in using superconducting cavities for high power accelerators in the future**

High Power Accelerators

- For elementary particle physics using high luminosity machines (factories)
  - **B factory**
  - **Phi factory**
  - **Tau-charm factory**
- To produce spallation neutrons using high energy protons
  - **Spallation Neutron Sources (SNS)**
  - **Accelerator production of Tritium (APT)**
  - **Accelerator Transmutation of Waste (ATW)**

Features of High Luminosity Accelerators

- High current ($I > \sim 0.5$ A) with many bunches
- Short bunch length ($< \sim 1$ cm) and small β function at the interaction point
- Double-ring collider in most cases

Challenges for Accelerators

- High current (short bunch interval) can cause strong coupled-bunch instabilities
- Growth rate of any instability must be lower than radiation damping rate or the value achieved with bunch-by-bunch feedback

$\Rightarrow$ Must lower (damp) higher-order mode (HOM) impedance, typically < 1 kΩ (mono-pole mode) and < several kΩ/m (dipole mode) per cavity

- Beam blow up with electron clouds

HOM Damped Cavities

- There have been three types of cavities
  1. **Use widely opened beam pipes, the cut-off frequency is higher than accelerating mode but lower than most HOMs (KEKB-SC, CESR cavities)**
  2. **Use wave guides, the cut-off frequency of which is higher than accelerating mode but lower than the HOMs (PEP II, DAFNE cavities)**
  3. **All the modes leak out BUT accelerating mode is reflected back by a choke structure (Choke-mode cavity)**

Single-Cell Superconducting Cavity is Suited for the 1st Type

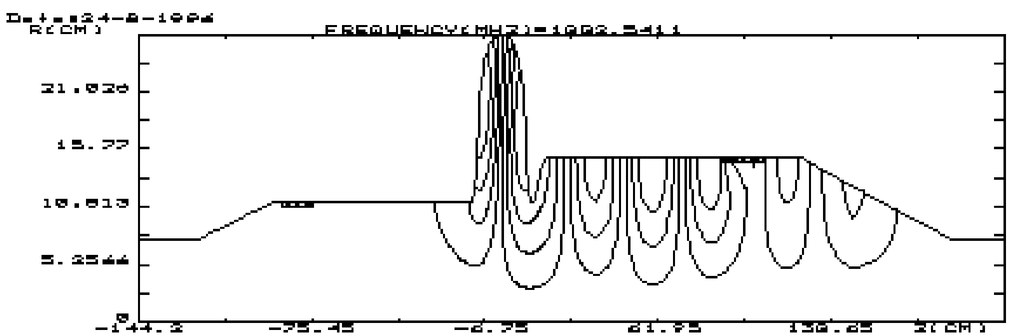
- High accelerating voltage can be kept with widely opened beam pipes
- It is possible to make all the HOMs travel out of the cavity through the beam pipes and be absorbed with absorbing materials (dampers) $\Rightarrow$ CESR, KEKB cavities

Concept of Single-Mode Cavity

- **Ideally, make all the HOMs leak out of the cell through beam pipes**
- **In reality, some dipole modes cannot leak out**

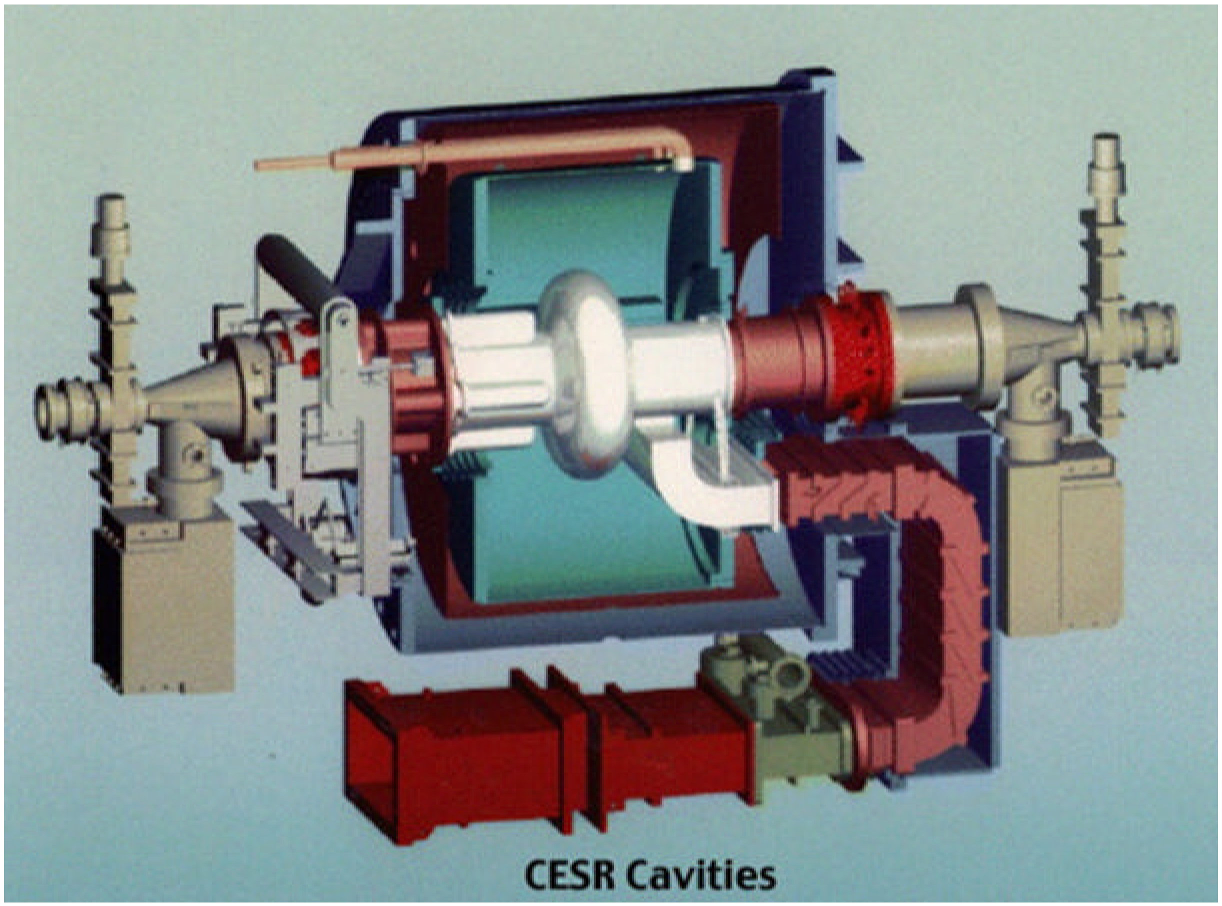
Þ **Fluted beam pipe (CESR)**

Þ **Partially enlarged pipe (KEKB)**



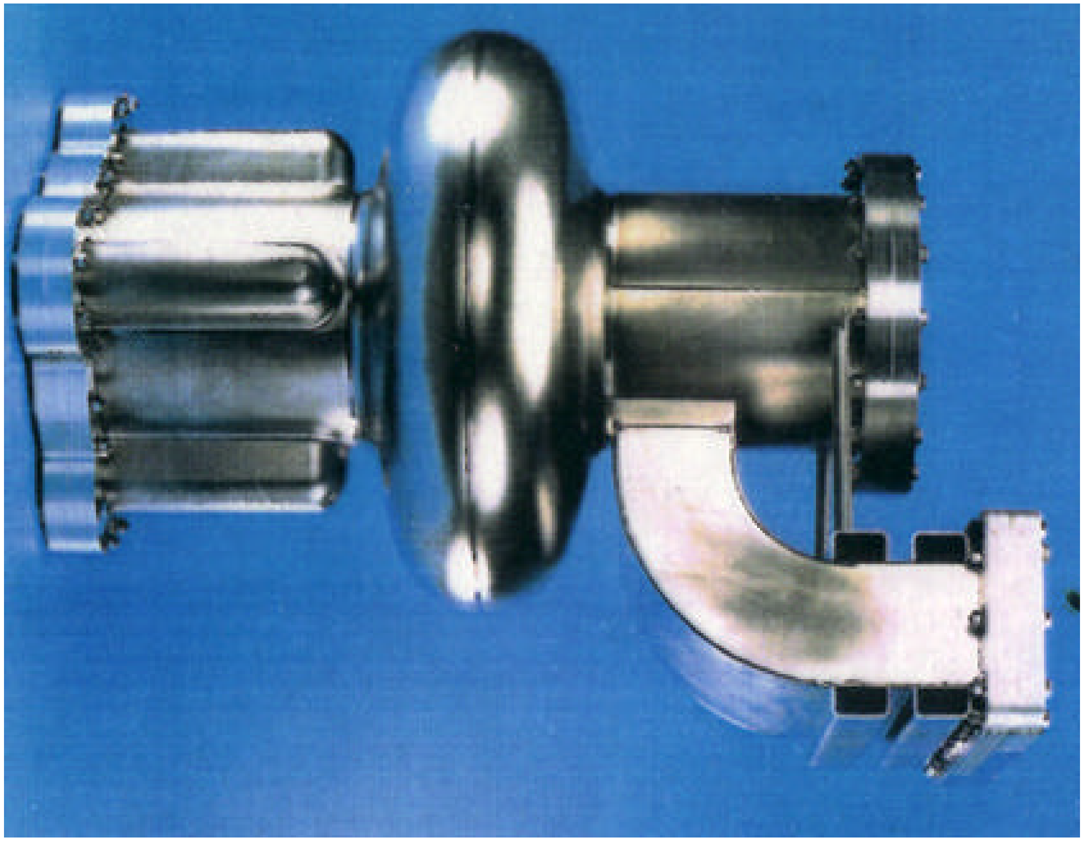
An example calculated with CLANS

CESR Superconducting Cavity Module

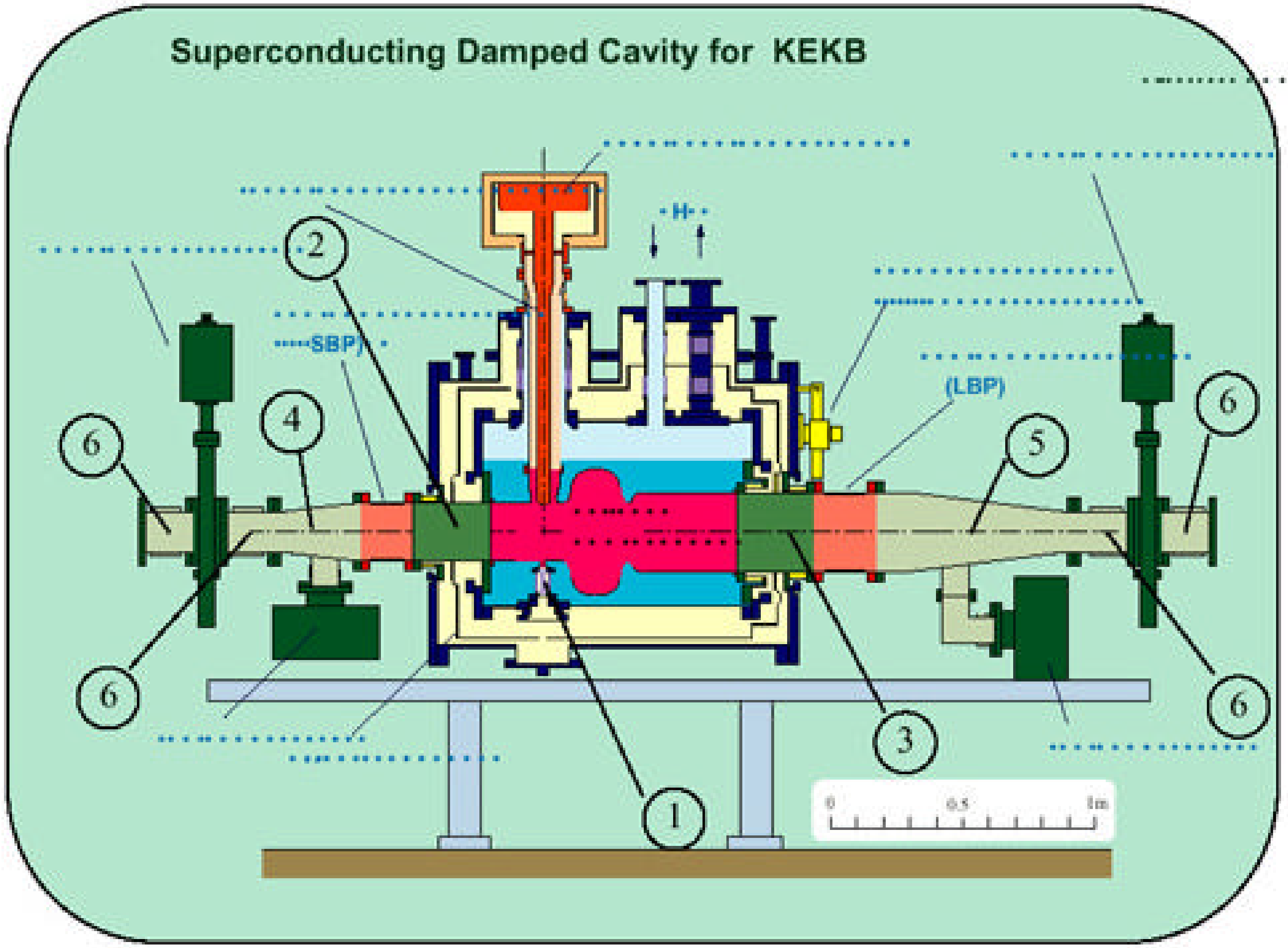


500 MHz

CESR Cavity

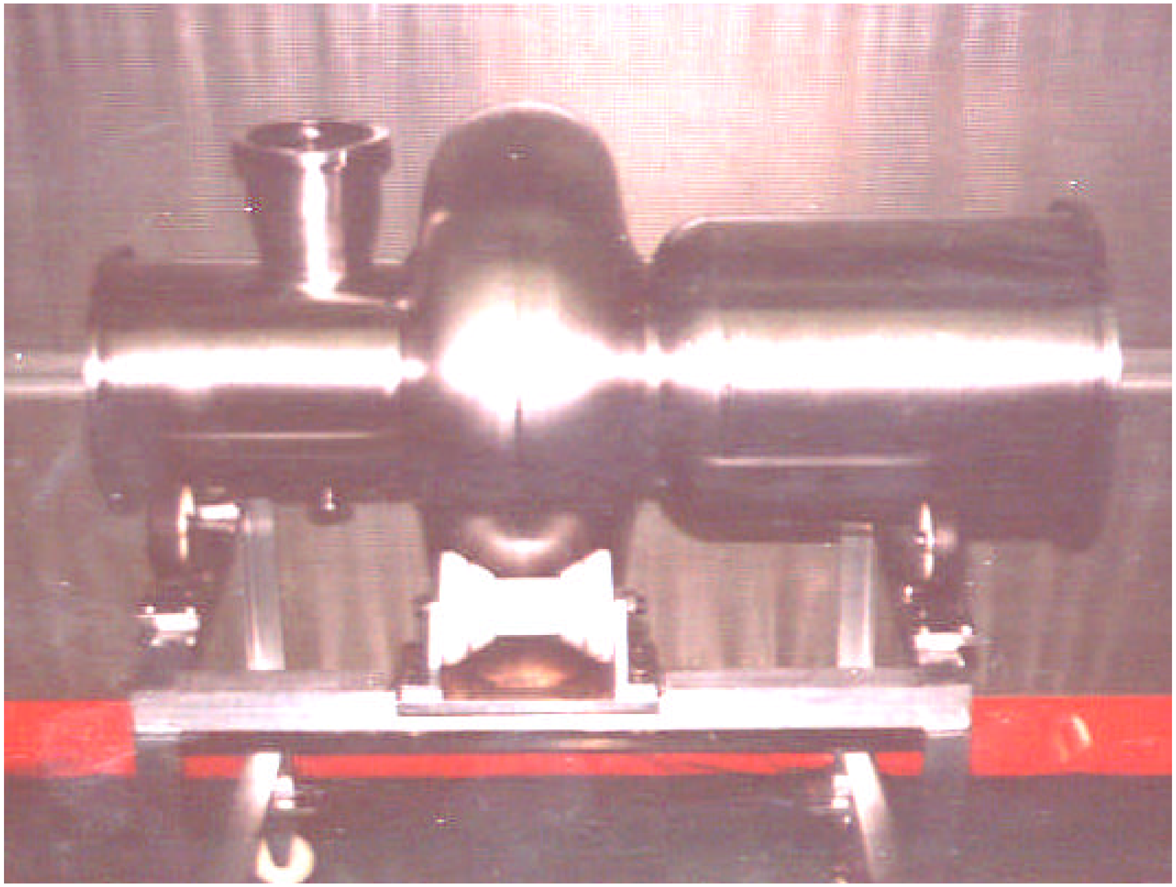


KEKB Superconducting Cavity Module

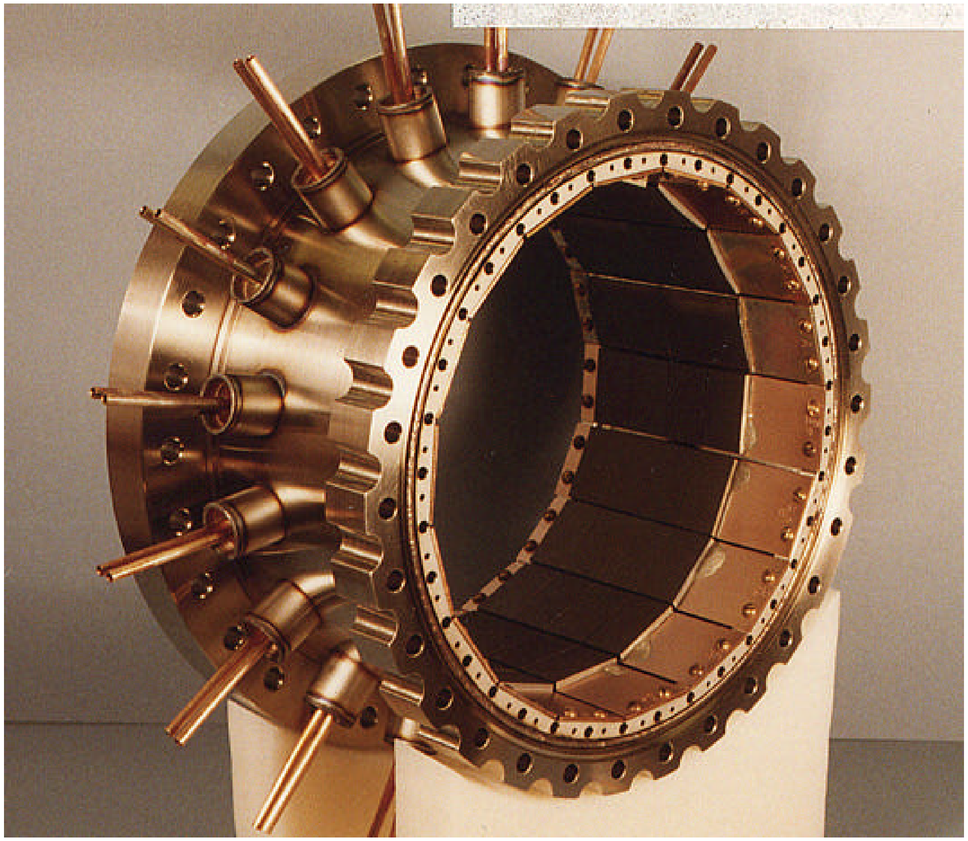


508 MHz

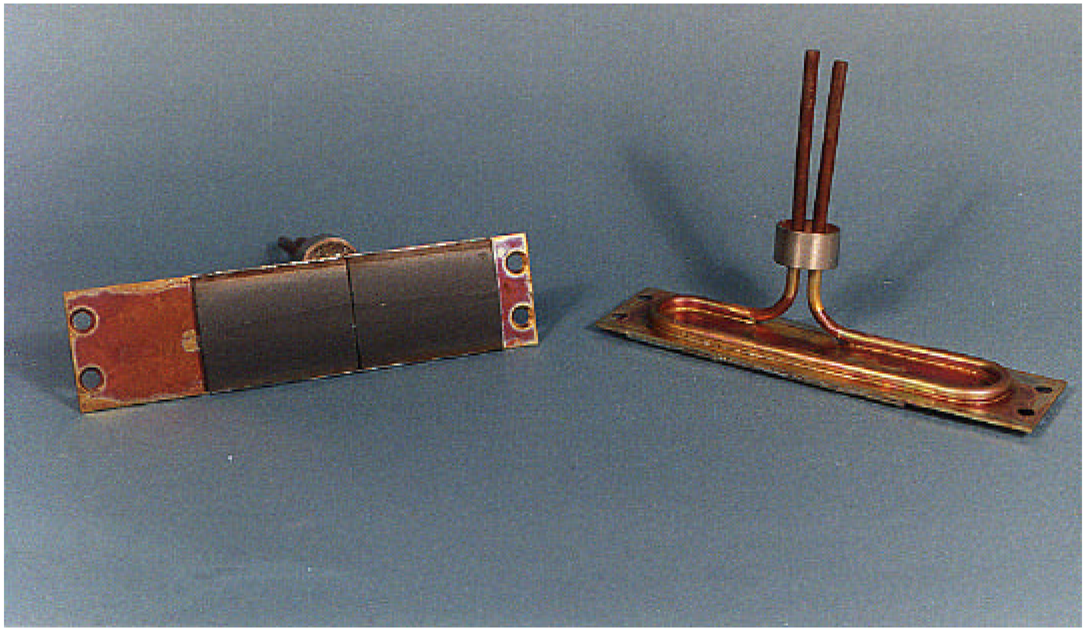
KEKB Cavity



CESR HOM Absorber

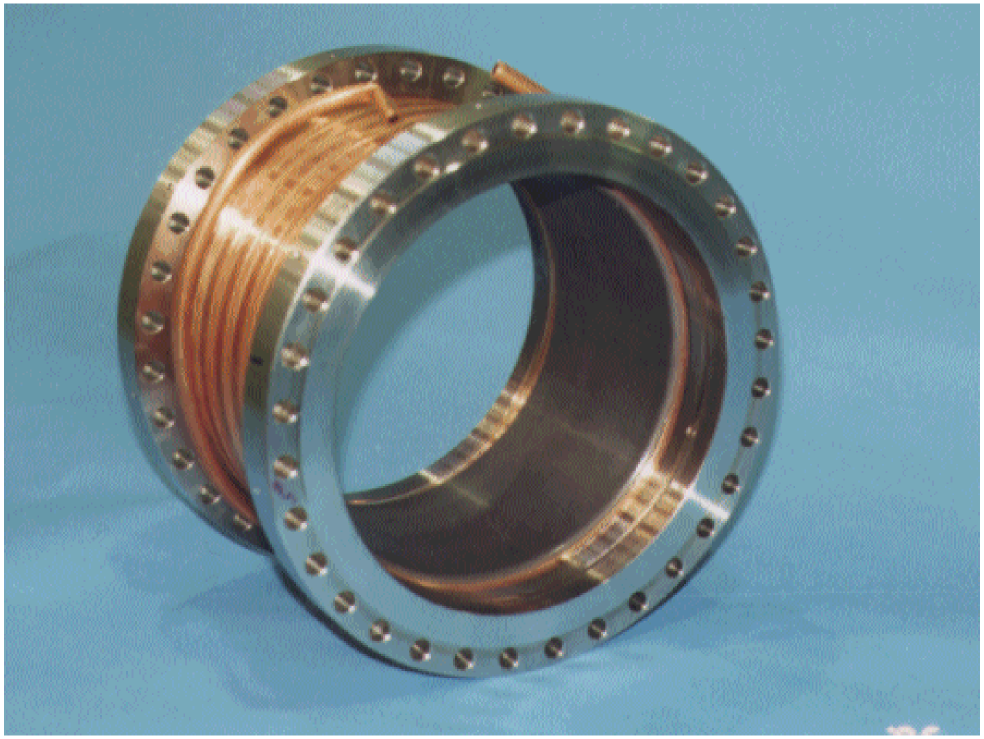


CESR HOM Absorber one assembled piece



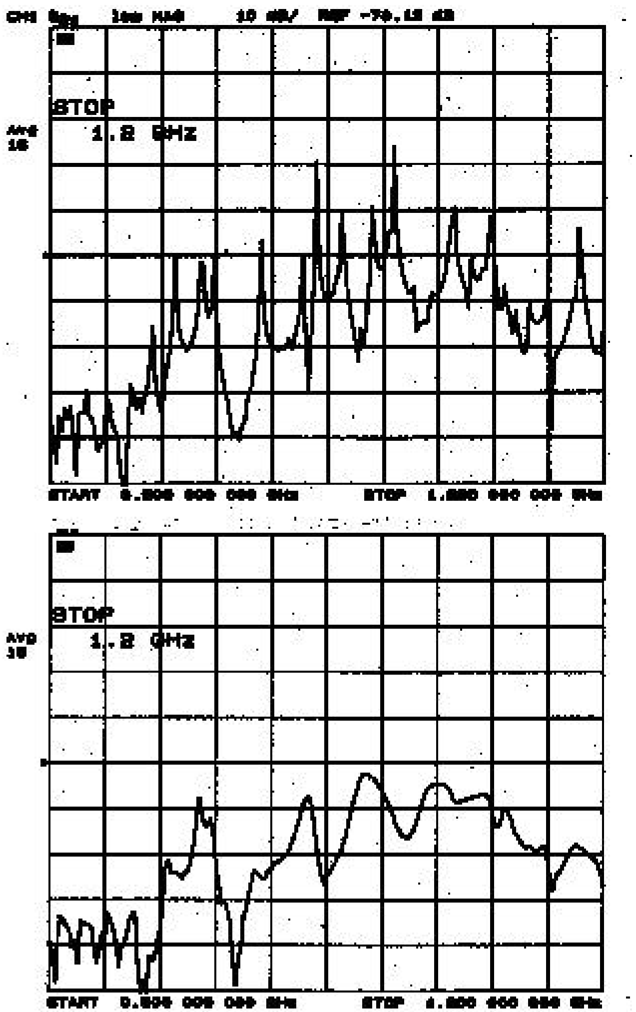
- 3.2 mm-thick ferrite tile
- Soldered onto Elkonite (58 % W and 42 % Cu), which has similar expansion coefficient with ferrite

KEKB HOM Absorber



- 4-mm thick ferrite
- Two ferrite sizes
  - 220 mm OD (120 mm long)
  - 300 mm OD (150 mm long)
- Sinter bonding of pre-sintered ferrite powder, a method developed at KEK

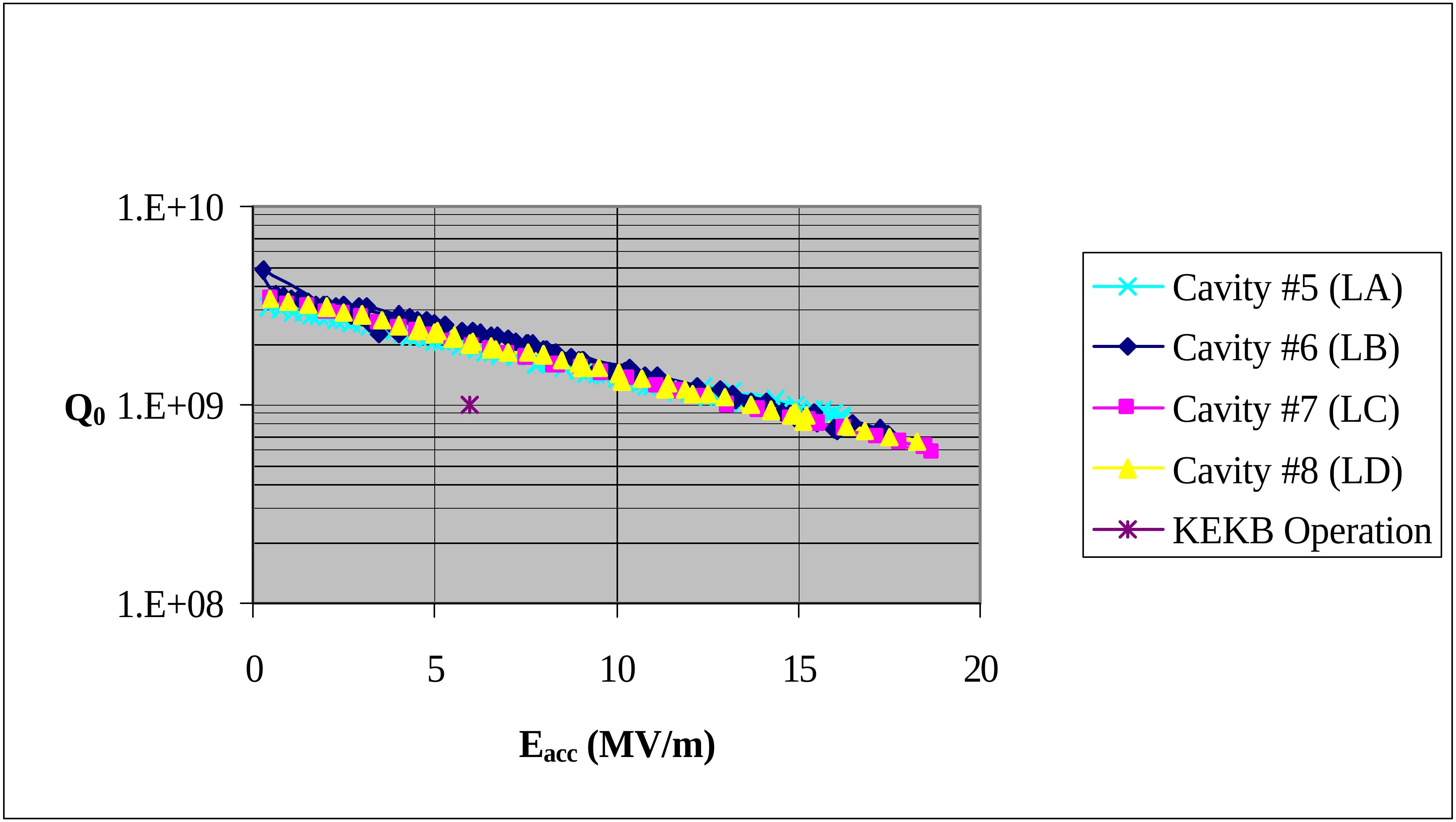
Mode Damping with Absorbers



Top: Without absorbers

Bottom: With absorbers

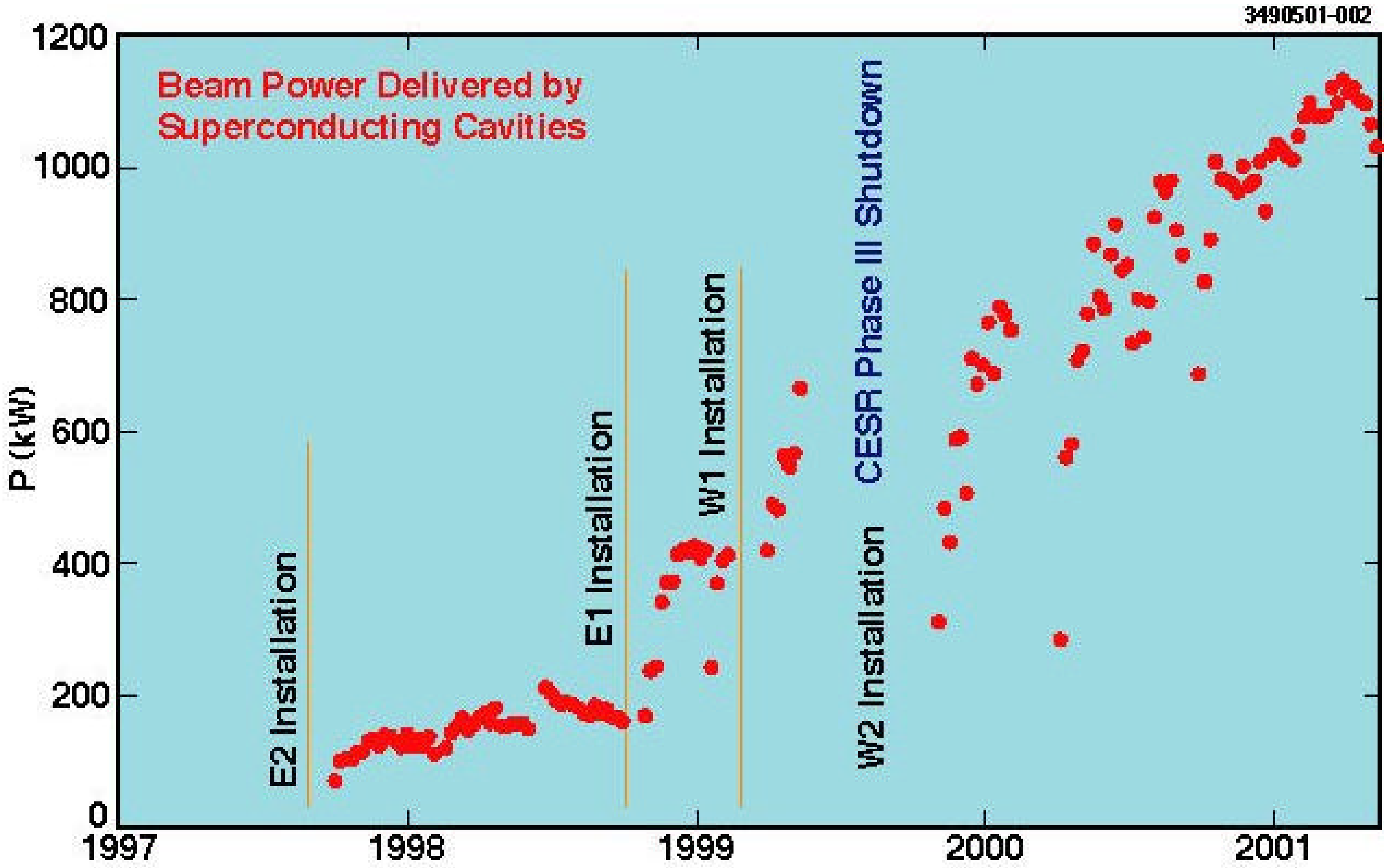
Performance of KEKB Cavities



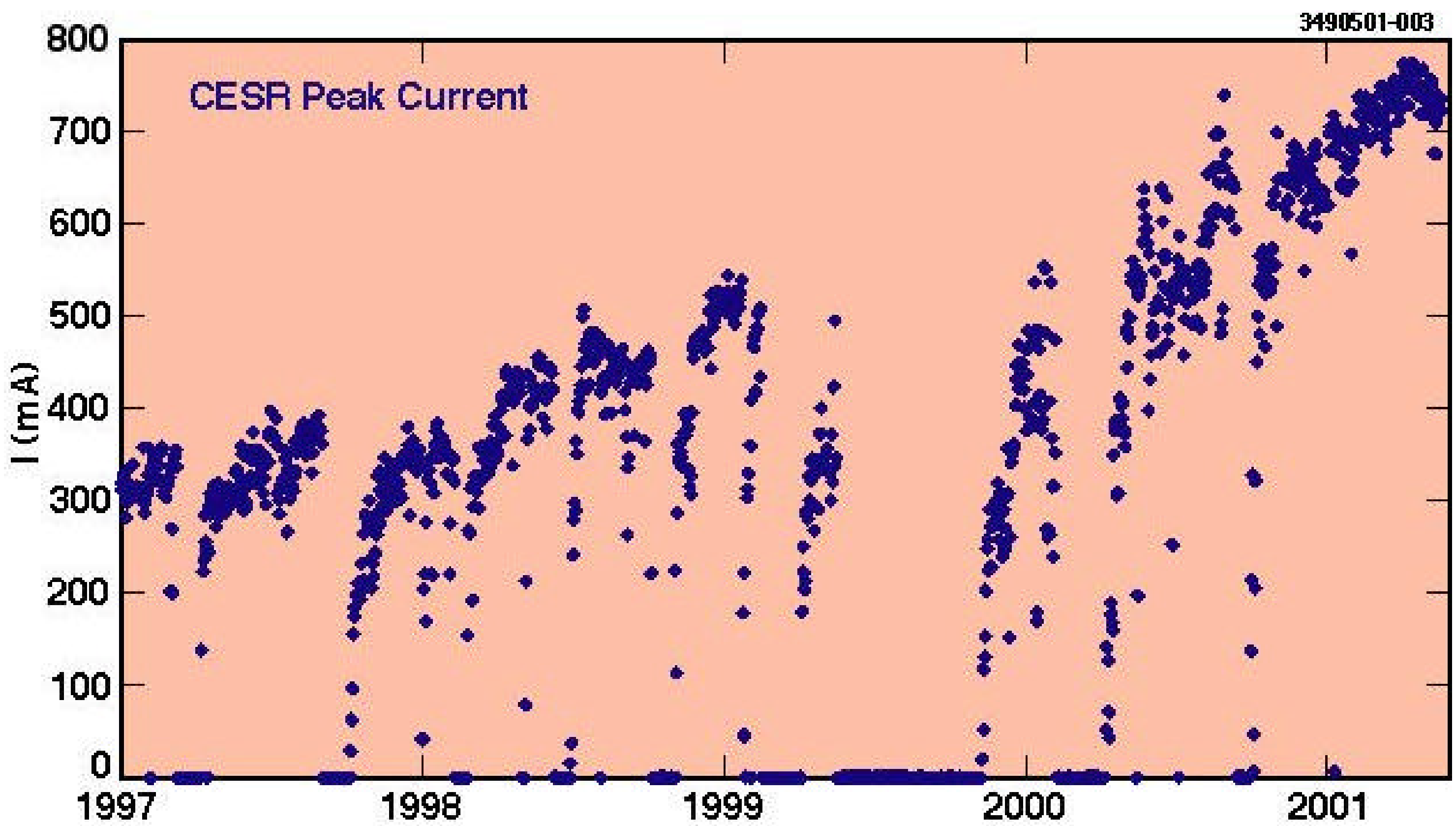
Present Status of CESR and KEKB Cavities (as of July 5, 2001)

- **CESR**
  - **Four cavities have been installed and a maximum current of 0.78 A with two beams has been achieved (design 1.0 A)**
- **KEKB**
  - **Eight cavities have been installed and a maximum current of 0.78 A has been achieved (design 1.1 A)**
- Both cavities have been very reliable (average RF trip rate is ~ once/2 weeks/cavity at KEKB)

CESR Beam Power History



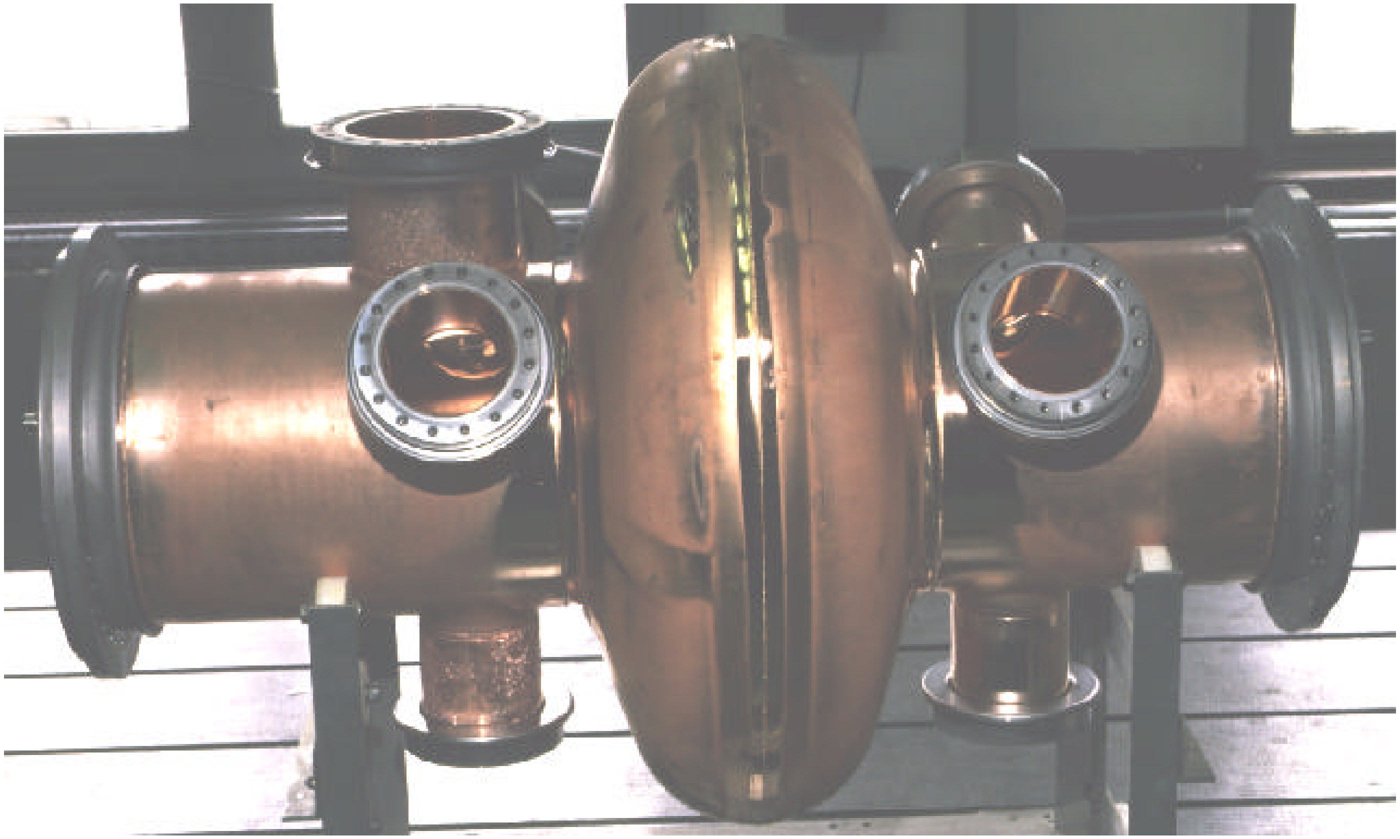
CESR Peak Current History



Superconducting Cavity for LHC

- Eight 400 MHz, single-cell cavities for acceleration of each 0.56 A proton beams
- Sputter Coating of Nb on copper technology used for LEP cavities is applied
- Design values
  - E_{acc} = 5 MV/m at 4.5 K
  - $Q_0 = 2 \times 10^9$ at 5 MV/m
- 300 kW/cavity will be delivered to beam
- Variable coupler based on LEP2 design will be used

LHC Superconducting Cavity before Niobium Coating

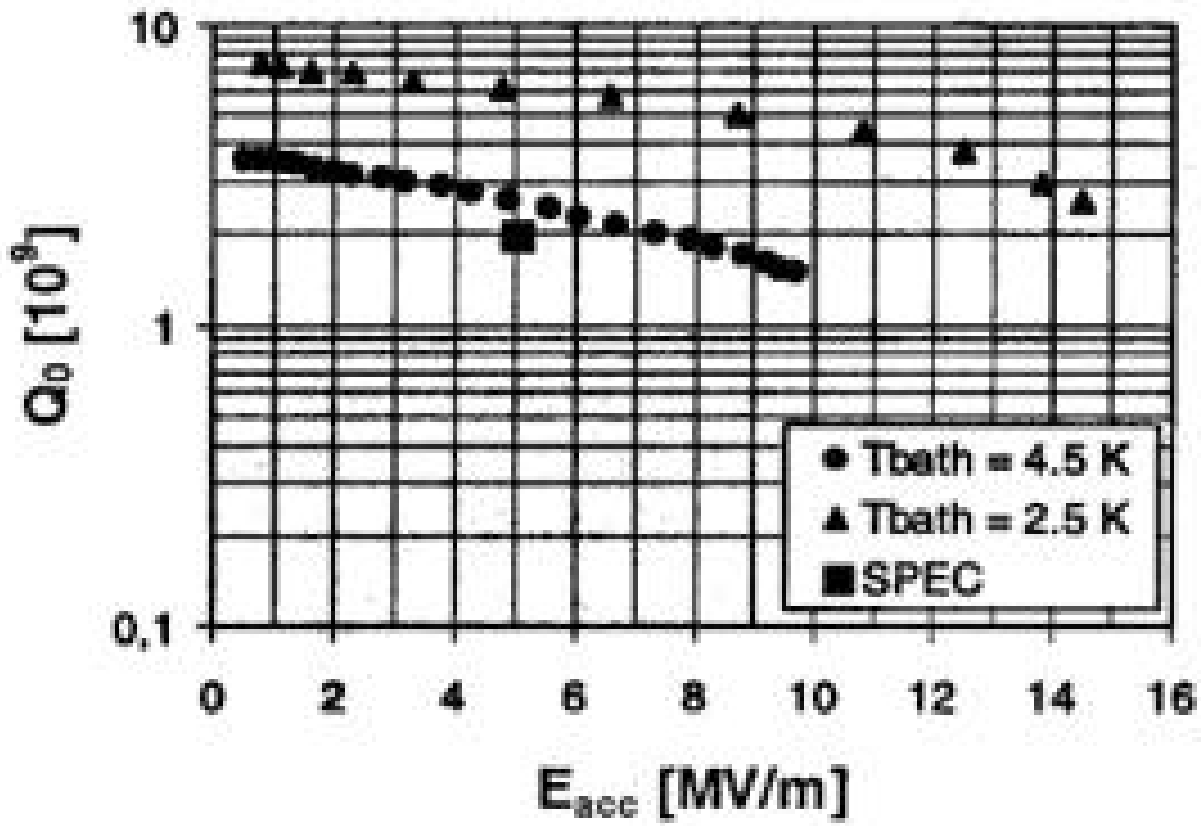


Beam pipe diameter: 300 mm

Equator diameter: 689 mm

Performance of LHC Cavity

(S. Bauer et al., SRF99)



High Power Proton Linacs

- Applications to use neutrons produced by spallation effect
  - Accelerator Production of Tritium (APT)

    $\Rightarrow$ 1 GeV, 100 mA CW Linac $\Rightarrow$ 100 MW
  - Spallation Neutron Sources (SNS)

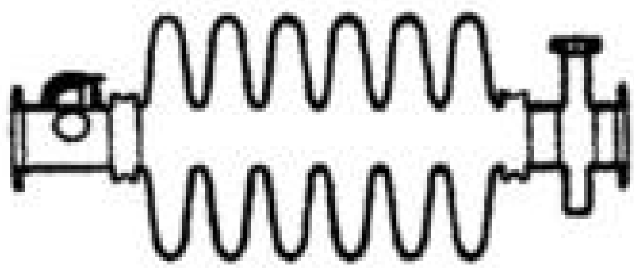
    $\Rightarrow$ 1 GeV, 26 mA (av. macropulse), 1.56 mA (average), pulse (60 Hz, duty 6 %) $\Rightarrow$ 1.56 MW (average)

Superconducting Cavities for Proton Linacs

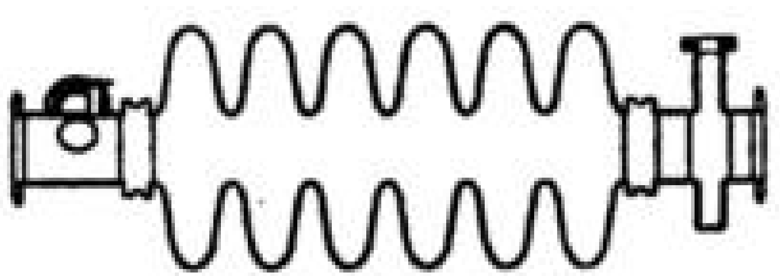
- Since beam current is relatively low, damped cavities are not necessary
- Multi-cell cavities, e.g., 5- to 6- cell cavities, have been designed/fabricated
- Because the particle speed is lower than light velocity, the cavity cell shape is changed accordingly

Superconducting Cavities for Proton Linacs (β=v/c > 0.45)

- **Foreshortened elliptical cavities for lower velocities (difference of shape Þ an example below)**



$\beta = 0.49$



$\beta = 0.64$

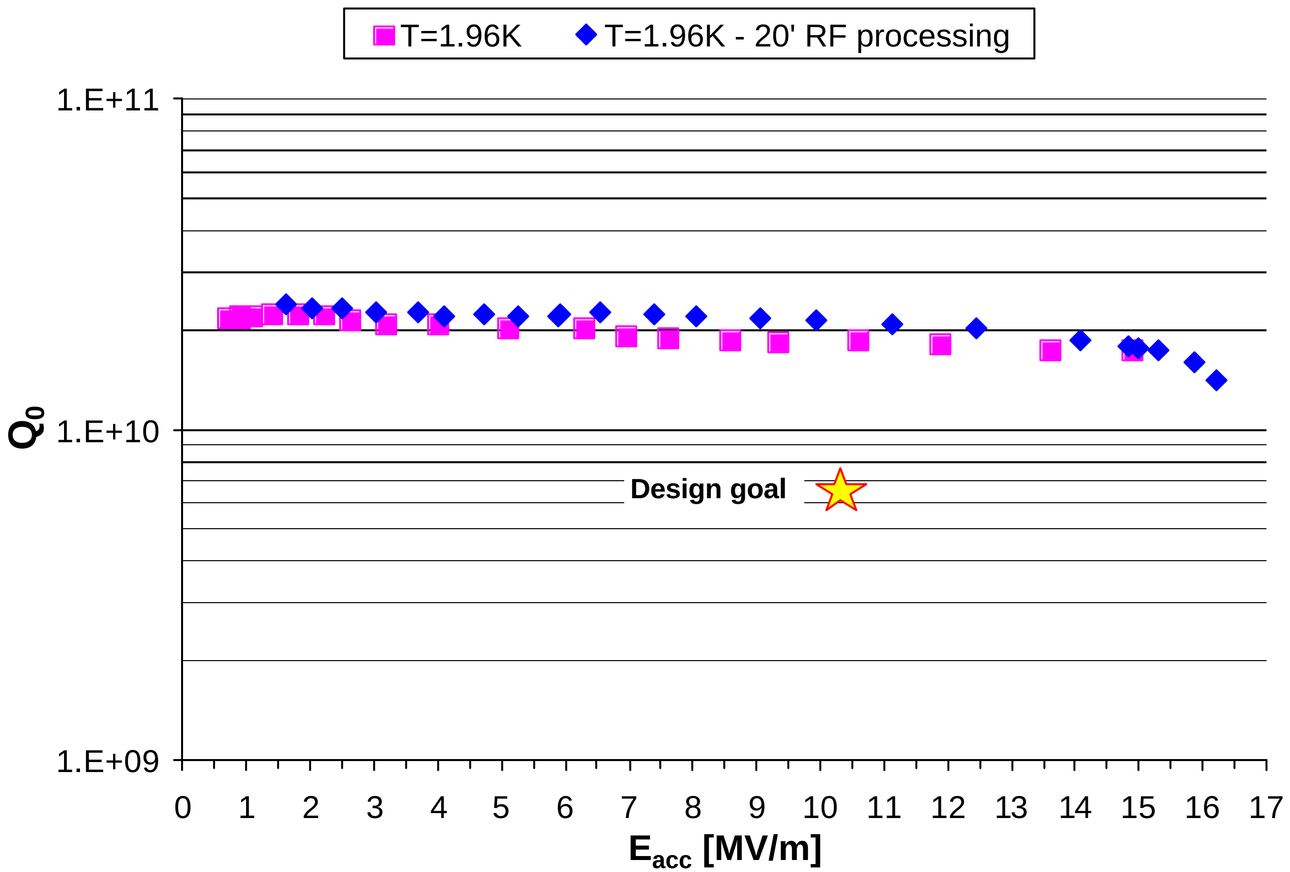
SNS Cavities (805 MHz)

(P. Kneisel et al., PAC2001)

$\beta = 0.61$

$\beta = 0.81$

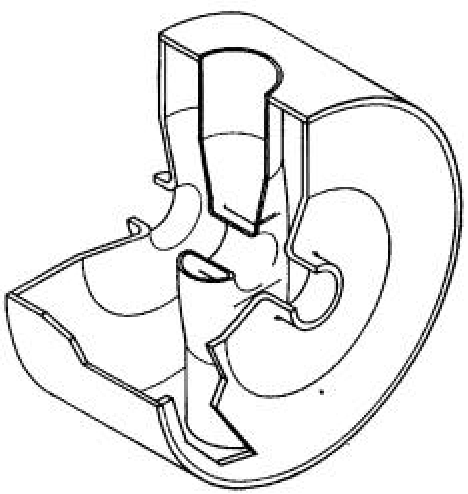
Performance of SNS Cavity



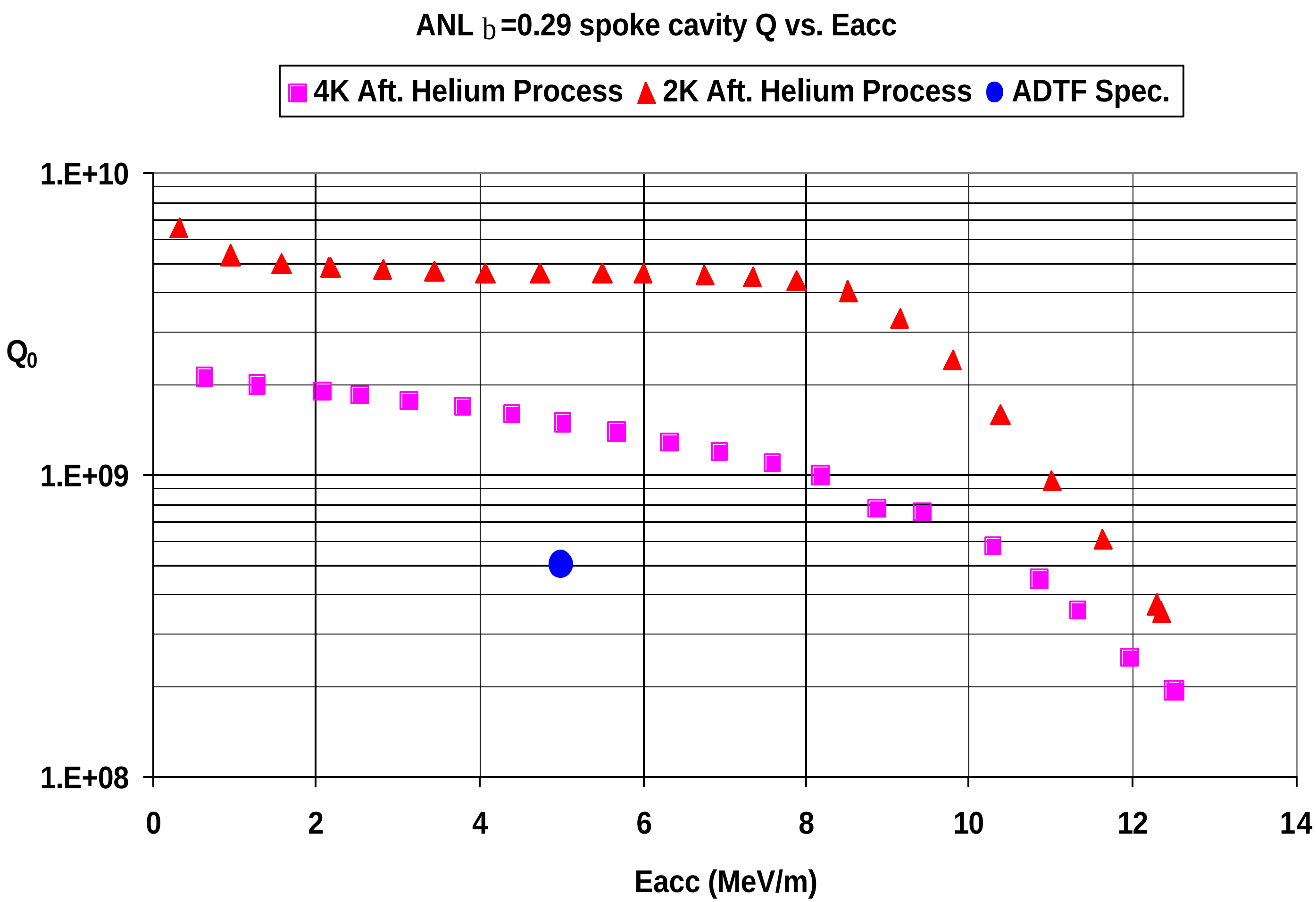
β=0.61

Superconducting Cavities for Proton Linacs ($\beta < 0.45$)

- Spoke resonator is a good candidate for this due to mechanical stability and small size compared to elliptical cavities



Performance of Spoke Cavity made by ANL and Tested at LANL

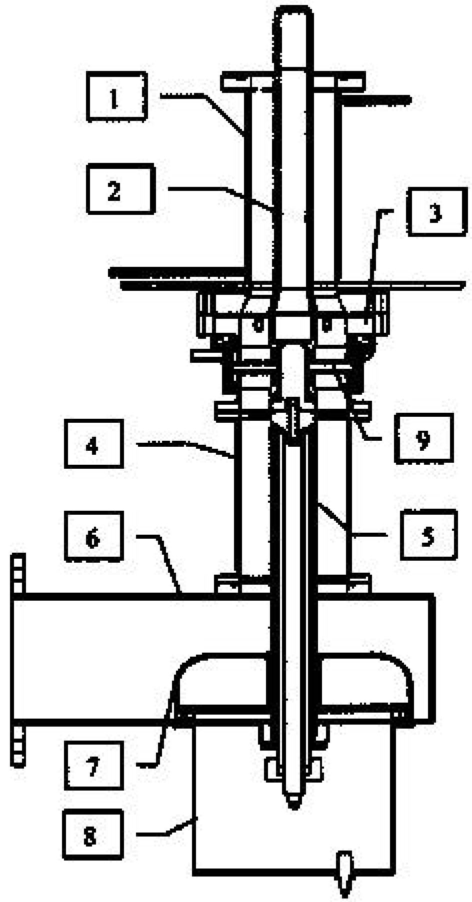


High Power Input Couplers

- Coaxial-type couplers are the main stream (APT, KEKB, LEP, SNS, TESLA)
- CESR (Cornell) uses waveguide-type coupler
- Present maximum power delivered to beam is ~ 380 kW (KEKB, design 240 kW)
- At the test bench, APT coupler has been tested > 1 MW TW. (design 420 kW)

SNS Coupler based on KEKB Coupler

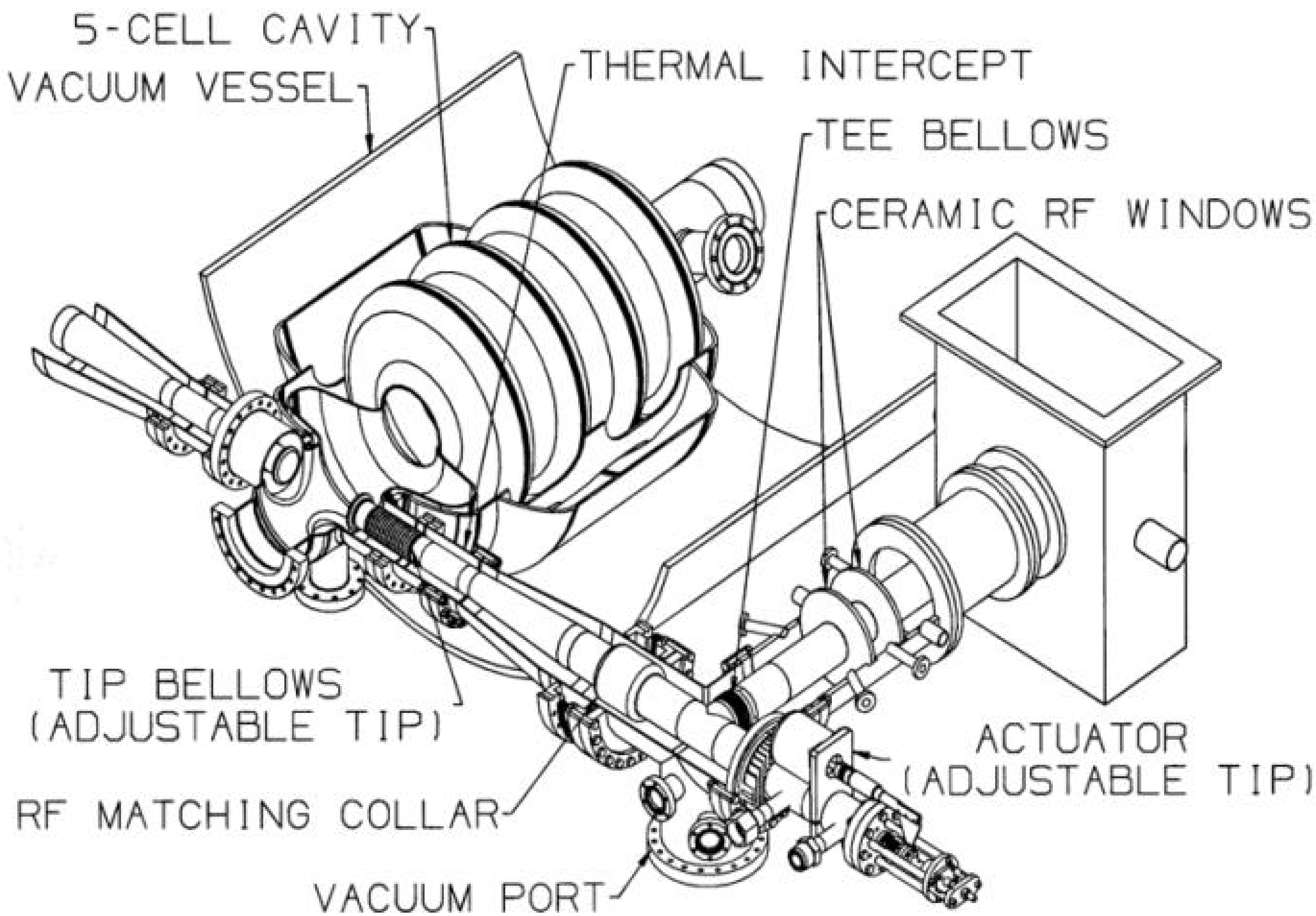
(Campisi et al., PAC2001)



1 – Outer Conductor
2 – Inner Conductor
3 – Window Assembly
4 – Outer Extension
5 – Inner Extension
6 – Waveguide
7 – Doorknob
8 – Waveguide Cover
9 – Ceramic Window

Figure 1: Fundamental Power Coupler.

APT Coupler


5-CELL CAVITY
VACUUM VESSEL
THERMAL INTERCEPT
TEE BELLOWS
CERAMIC RF WINDOWS
TIP BELLOWS
(ADJUSTABLE TIP)
ACTUATOR
(ADJUSTABLE TIP)
RF MATCHING COLLAR
VACUUM PORT

Issues on Power Couplers

- Multipacting ⇒ Coaxial lines are well understood and DC biasing can avoid this
- Gas condensation on a cooled surface and related enhancement of electron emission coefficient ⇒ Can lower the effect with additional pumping and by reducing outgassing rate from window
- Discharge/arc from ceramic window ⇒ Eliminate cold window, thin TiN coating of the surface and degassing with baking can reduce this problem

Issues on Superconducting Cavities for Higher Power Accelerators

- For higher current applications (a few amperes)
  - The single-mode cavity seems to work well
  - ED&D of absorbers that can handle higher power will be necessary (shape, higher thermal conductivity material, etc.)
  - Power coupler may still work well at higher power with better thermal management